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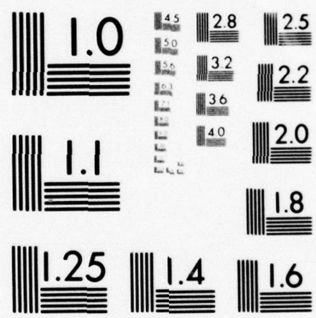

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SUMMARY OF BUCKLING AND TENSION TESTS OF LANDING MATS AS RELATED TO C-5A AIRCRAFT BOW WAVE PROBLEMS

by

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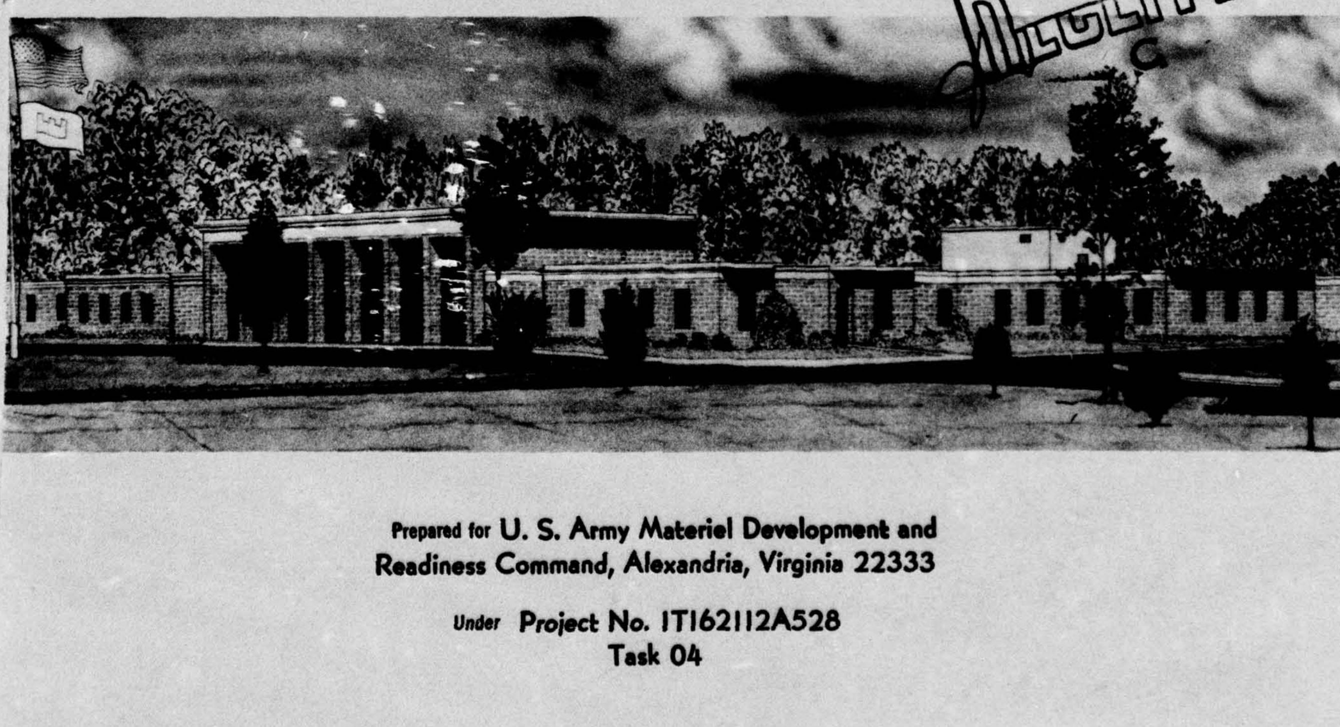

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In order to better understand and define the problems associated with the C-5A and landing mat, several investigations were conducted at the U. S. Army Engineer Waterways Experiment Station and Utah State University to study the characteristics of landing mats subjected to horizontal C-5A loads. Several mat configurations with various connector designs were evaluated in buckling, skid, joint slack, and traffic tests. Mats both with and without water seals were used in the tests; however, the heavy-duty truss web mat designs with their extra weight and additional strength were given primary consideration.

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20. ABSTRACT (Continued)

In the buckling tests conducted, it was determined that panel width, mat unit weight, and formation width were factors which affect the buckling load of a mat system. The horizontal load at which buckling occurs depends almost exclusively on the vertical eccentricities existing in the mat system at the time the load is applied. These eccentricities or irregularities could be initiated by the presence of warped panels, damaged joints, uneven subgrade, etc.

It is concluded that the approximately square truss web mat design sustained a much higher load per foot of width prior to the development of a bow wave or buckling. Square mats without water seals give higher resistance to sliding between mat rows than mats with seals. However, membrane beneath mat provides a lower coefficient of friction which enhances mat sliding. During the normal placement of mat, there is free slack in the panel joints which, although necessary for contraction and expansion, contributes to potential runway movement.

Based on the findings of this study and similar studies involving mats which appear capable of satisfying the C-5A aircraft requirements, it is recommended that the heavy-duty truss web mat, with inherent waterproofing and laid with the internal extrusions perpendicular to traffic and the male/female joint continuous and transverse to traffic, be developed for the C-5A. Improvements should be made to the square truss web mat and the mat field tested with the C-5A aircraft. The anchor restrictor should be tested further and also included in a field test. An end anchorage system should be developed and evaluated.

Appendix A:

Buckling and joint slack tests were conducted on several types of landing mat designs to determine various movement characteristics of these designs. The buckling tests consisted of placing the mat panels on a test section. A ram with a rated capacity of 50 kips was attached at one end of the section and the opposite end of the section was anchored. The force on the ram was applied at a constant rate during the tests. The M19, 4- by 4-1/2-ft truss web, and 2- by 9-ft truss web mats were subjected to tests. The force required to buckle these mats was recorded. The M19, 2- by 9-ft truss web with and without waterproofing seals, and 4- by 4-1/2-ft truss web mat sections were subjected to joint slack tests. Each section consisted of 11 panels of one type mat. The panels were placed normally (not jammed together or pulled to take out the slack in the joints). A dynamometer was used to measure the amount of force required to move the mat. The total amount of mat movement which occurred after all slack was taken out of the panel joints and the last panel in the section began to move was recorded.

In sections wider than a full panel width, the 2- by 9-ft truss web mat sustained the highest buckling load and the M19 mat sustained the next highest buckling load. The truss web mat is a stiffer, heavier mat than the other mats tested, and the M19 mat sustained a high resistance to the buckling load from inherent stiffness generated by its placing pattern.

The mat joint slack tests revealed that the amount of force required to move the mat depended on the mat weights, and the total mat movement depended on whether the mat was placed with the joints jammed together or all slack removed. These results indicate that when the mat is placed with all slack removed from the joints (tension mat panels as they are laid), the amount of mat movement is reduced.

Appendix B:

Sliding resistance tests were performed on XM19-D1 mats with and without waterproof seals to determine which had the greater resistance to a sliding force similar to that produced by braking aircraft. Test results indicated that the waterproof seals contributed substantially to the resistance to sliding.

Coefficient of friction tests were performed with painted and antiskid-coated mats on a loess subgrade (approximately 20 CBR) and on a heavy clay subgrade (approximately 6 CBR) for comparison. The test results revealed that the antiskid coating gave 14 to 30 percent higher values than the paint, depending on the subgrade.

Tests were also performed to determine mat movement and mat rebound under aircraft skidding. Maximum mat movement measured was 1/4 in. and rebound was 0.06 in. During the tests, the change in mat elevation and in the location of the tire was recorded periodically. These data indicated that the panel was elevated a maximum of 0.6 in. when the tire was on the opposite edge of the panel. The lowest elevation of a panel occurred when the load wheel was on a panel which was over a subgrade void or over a low-strength subgrade.

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PREFACE

The summary reported herein was prepared at the U. S. Army Engineer Waterways Experiment Station (WES) as part of the landing mat program under "General Purpose Expedient Engineering Materiel," DA Project No. 1T162112A528, Task 04, under sponsorship of the Research Division, Research, Development, and Engineering Directorate, U. S. Army Materiel Development and Readiness Command.

This summary was prepared during the period January-June 1976 under the general supervision of Mr. James P. Sale, Chief, Soils and Pavements Laboratory (S&PL). Personnel of the Materiel Development Division, S&PL, actively engaged in the planning, analyzing, and reporting phases of this study were Messrs. William L. McInnis, Hugh L. Green, Dewey W. White, Gordon L. Carr, and Carroll J. Smith. This report was written by Messrs. Green and Smith.

Directors of WES during the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. The Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
square feet	0.09290304	square metres
pounds (mass)	0.45359237	kilograms
tons (2000 lb, mass)	907.1847	kilograms
pounds (force)	4.448222	newtons
kips (force)	4.448222	kilonewtons
pounds (force) per square inch	6.894757	kilopascals
degrees (angle)	0.01745329	radians

SUMMARY OF BUCKLING AND TENSION TESTS OF LANDING MATS AS RELATED TO C-5A AIRCRAFT BOW WAVE PROBLEMS

INTRODUCTION

Background

1. The C-5A aircraft was designed to have the capability of sustained operations on support area airfields, which include expedient airfields surfaced with landing mat. Tests were conducted by the Air Force at Dyess AFB, Texas, during August 1970 to evaluate the performance of the C-5A aircraft on landing mat. During this demonstration of the capability of the C-5A to operate on the existing expedient airfield at Dyess AFB, the following problems developed:[1]

a. During an engine runup in the area of a 90-deg* connecting taxiway, the blast generated by the 40,000-lb thrust of the outboard engines on one side of the aircraft caused a lifting and rolling over of a 60-ft-wide section of the connecting taxiway of M19 landing mat.

b. On the fourth landing of the C-5A with a 470,000-lb gross weight and while the aircraft was braking, a portion of the runway surfaced with AM2 landing mat shifted. The cumulative mat shifting in the direction of landing resulted in the formation of a bow wave ahead of the main gear, and overriding of this bow wave resulted in panels thrown in the air as high as 30 ft, resulting in punctures and dents in the aircraft and tire damage.

Purposes

2. Until this incident, the C-5A was considered to be a candidate for operating on light-duty mat since it was a cargo aircraft and the flotation requirements for support of its 24 main gear tires were within the C-130 range. However, the Dyess incident immediately demonstrated the need for additional considerations in the area of the braking of an aircraft of this size. Thus, even though the Dyess landing mat field was 4 yr old and had experienced much usage, the incident proved that proper attention had not been given to the massive horizontal forces exerted by heavy aircraft with multiwheel gears during the braking phase of operation.

3. In order to better understand and define the problems which are associated with the C-5A and landing mat, several investigations were conducted to study the relationships between the C-5A and landing mat. These tests and studies were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) and Utah State University to study the buckling characteristics of landing mats subjected to horizontal C-5A loads. These works are described in the following paragraphs along with results of two traffic tests on C-5A landing mat candidates.

SYNOPSIS OF INVESTIGATIONS

Buckling Tests

4. *Full-scale laboratory tests.* Studies were conducted using various landing mats and lay patterns

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

to define and evaluate the parameters which affect the stability of mats subjected to horizontal forces.[2] The primary work was accomplished by conducting an extensive series of full-scale static buckling tests in the laboratory. The mat test section ranged in width from one to five panels, with a maximum section width up to 36 ft. Mats used in the tests were the AM2, XM18, and M19 along with XM18 mats with simulated waterproofing. It was found that panel width, mat unit weight, and formation width were factors which affect the buckling load of a mat system. However, the most predominant factor affecting the buckling load was the initial eccentric characteristic of the mat system. This eccentricity is normally caused by an irregular subgrade in the field. The locking angle of the mats varied, but it had no effect on the buckling load; however, it did affect the profile of the buckled wave. The presence of fillers inserted in the joints to simulate waterproofing the mats reduced the locking angle but did not allow for an increase in the buckling load.

5. *Tests with scale-model AM2 mats.* A series of buckling tests utilizing scale-model AM2 mats obtained from Utah State University was conducted in the WES laboratory. The widths of the small-scale test sections ranged from 0.86 to 13.8 ft (equivalent to 6- to 96-ft sections in prototype scale). The 96-ft width corresponds to that of the prototype mat runway at Dyess AFB. Results from the scale-model tests enabled the extrapolation of results for full-scale buckling tests from narrow widths in the laboratory to mat sections of greater widths.

6. After attempts were made at WES to develop a mathematical model to compare scale-model behavior with the buckling behavior of the prototype mats, it was found that the horizontal load at which buckling would be initiated depends almost exclusively on the vertical eccentricities existing in the mat at the time the load is applied. Because of the random nature of initial irregularities of a real system (e.g., warped panels, damaged joints, uneven subgrade), the initial buckling load is an unreliable measure of the load-carrying capacity of the system. Therefore, further elaborate mathematical analyses directed toward a more exact determination of initial buckling load or of sustained post-buckling resistance were believed to be unwarranted.

7. It was determined that revisions such as resilient filler insertions or alternative lay patterns which increase the stability of the mat may enhance the post-buckling behavior and may increase the initial buckling load.

8. *Tests with prototype truss web mats.* Further landing mat buckling tests were conducted on full-size panels of heavy-duty truss web mats (see Appendix A). The mat was placed in test sections ranging in size from 9 by 22 ft to 36 by 22 ft, utilizing both the square (4- by 4-1/2-ft) and the standard (2- by 9-ft) truss web mats. The loading device was a 50,000-lb-capacity hydraulic ram, and the method of anchoring the mat on the opposite end from the loading device consisted of bolting the last row of mat to the supporting surface.

9. Since after the Dyess incident, the heavier truss web mat design with a weight of 6.3 to 6.5 lb per square foot was envisioned as being the prime C-5A mat candidate, both the square and standard versions of the truss web mat were investigated, and the square mat was studied in two different laying patterns. The mat panels used in this investigation had an average weight of 6.3 lb per square foot. In each test, 11 joints were included in each complex, and as a basis for comparisons the load per foot of width of panel that caused buckling will be discussed.

10. Results showed that both lay patterns of the square truss web mat had a much higher load per foot of width prior to buckling than the lay pattern of the standard mat. Buckling of the two lay patterns of square mat indicated that the mat laid with the connector bars parallel to the load line sustained a 28 percent greater loading than that laid with the bars perpendicular to the load line. The minimum load to

buckle truss web mat was 1400 lb per foot of panel width. This occurred on the standard 2- by 9-ft mat in its normal laying pattern in which the male/female connectors are perpendicular to the load line.

11. *Tests with scale-model truss web mats.* A series of scale-model tests was conducted by Utah State University on square and standard model (1/7 scale) truss web mat to simulate C-5A landings on landing mat runways.[3] Dimensional analysis and similitude were used to equate the variable conditions for the model and prototype. The truss web mats were fabricated and tested on a scale-model of a 128- by 14-1/2-ft runway using a model C-5A landing gear. The two mat types were tested under varying aircraft weights, velocities, and decelerations. Various modifications of lay patterns and restraint conditions were studied, and failure characteristics were observed and used to develop mat alterations to improve the performance of landing mat runways.

12. Comparisons were made of the buckling action and dynamic response of the square and standard mat runways in the standard Dow lay pattern (male/female connectors forming a continuous joint perpendicular to the landing direction). Tests on unrestrained runways showed that the square mat runway required a greater force to cause buckling than standard mat runway. The square mat runway also demonstrated greater stability than the standard mat runway.

13. The square mat was also tested in two laying patterns with continuous longitudinal joints parallel with the direction of landing. The first pattern, termed the alternate brick pattern, was formed with the locking bar edge of the mats forming a continuous longitudinal joint. The second pattern was the 90-deg rotated standard Dow lay pattern with the male/female connector forming a continuous longitudinal joint. Longitudinal movement and dynamic response measurements were lower for these two lay patterns than for the square mat runway in the standard Dow lay pattern. The two runway patterns with continuous longitudinal joints provided a much stiffer runway which did not buckle.

14. Edge restraint tests to simulate edge tie-down anchors were conducted on the 2- by 9-ft mat model runway in the standard Dow lay pattern. The tie-downs proved to be ineffective in preventing a buckling failure, and the dynamic response of the runway was only temporarily reduced by the edge tie-downs. Longitudinal movement along the runway edge was prevented by pinning the runway edges but displacement at the runway center line was sufficient to develop a buckling failure. The braking forces at the runway center line and the fixed points at the edge could cause the development of a large bow of the continuous joint. This bow transfers large stresses on the mat end joints and could cause end joint weld failures.

15. The square model mat was tested in a 26-deg diagonal lay pattern. This pattern was only slightly more stable than the standard Dow lay pattern. Results indicate that the continuous joint of the standard Dow lay pattern must be set at an angle greater than 26 deg to have any significant influence on the mat stability and buckling potential.

16. Tension anchors were placed at the ends of the model runway to evaluate their control on longitudinal displacements and thereby their reduction of potential buckling. Both model mat runways in the standard Dow lay pattern survived 100 test landings without failure. The dynamic response of the mat was much less than for the unrestrained mat runway.

17. Due to the length of a prototype runway, problems could develop because of the limited influence of the tension anchor. If the mat joints are stretched to a full open position in a long runway, then adjacent runway lengths could act as an anchor for central portions of the runway. However, if mats are placed with some joints not fully open, then longitudinal movements could lead to zones of compressed mat and potential buckling. Results indicate that a carefully constructed runway with end anchorage appears to be a practical means to reduce maintenance on mat runways.

Joint Slack Determinations

18. An investigation consisting of mat placement and mat pull tests was conducted on various landing mat designs to study the amount of available slack at the mat joints when located in a mat complex and to determine the amount of mat movement which can occur at mat joints (see Appendix A). Mats studied included the M19 (4 by 4 ft), standard truss web (2 by 9 ft), truss web with waterproofing seals (2 by 9 ft), and square truss web (4 by 4-1/2 ft). The mats were placed in their respective normal placement patterns and allowed to join in the normal manner, not intentionally jammed together or pulled apart to take out slack. The M19 mat was pulled in the direction of the overlap/underlap joints and the truss web in the direction of the male/female joints, which are the normal laying patterns for each type mat. Ten joints were involved in each pull test.

19. The square truss web mat had the greatest amount of movement and the M19 demonstrated the least amount of movement in the joints. The average movement at a joint ranged from 0.011 to 0.034 in.; however, the maximum in each extreme could range from 0 in. to as much as 0.21 in., depending on whether the joints were completely open or completely closed.

Skid Tests

20. In the past, the primary function of landing mat anchors has been to prevent vertical movement of the runway edges under aircraft traffic. Horizontal movement in the past had not been considered a problem, since the rolled steel and aluminum designs and the open-bottom extruded designs (T11) presented a bottom bearing surface that was of such a type as to restrict horizontal movement along the subgrade surface. Also, the total gross weights of the using aircraft were not as large as that of the C-5A and thus did not generate the massive horizontal braking forces. With the advent of heavy cargo aircraft and the use of membrane beneath smooth-bottom mats, it became evident that additional data were required to determine the forces necessary to restrain landing mats.

21. Antiskid materials are normally placed on the top surfaces of landing mats to prevent aircraft skids, especially during inclement weather. Tests have been conducted in the past using a specially designed 30,000-lb skid cart to determine the coefficients of friction for the various antiskid-coated mats. Previous testing has shown the average coefficient of friction for mat with an antiskid surface to be approximately 0.67 and for mat with a painted surface to be approximately 0.40.

22. To acquire additional data in this area, especially on the horizontal forces required to prevent mat movement beneath a skidding aircraft tire and the coefficient of friction readings on the bottom mat surfaces, additional tests were conducted using a skid cart simulating a single-wheel loading of the C-130 aircraft.[4] Skidding was conducted on mats with and without antiskid placed both on membrane and on natural ground. Dynamometers were located between the mat and the mat anchor (when used) and between the towing device and skid cart to determine the horizontal forces being generated during the various combinations of pulls.

23. Results of these skid tests revealed the following coefficient of friction readings listed in increasing order: tire to painted mat - 0.49; painted mat to membrane - 0.51; antiskid-coated mat to membrane - 0.54; antiskid-coated mat to soil - 0.56; painted mat to soil - 0.59; and tire to antiskid-coated mat - 0.69. Only the coefficient of friction of the painted mat to soil was not in the anticipated order, and if one of the high pull tests in this group were eliminated, the average reading would be almost the same as the reading of 0.56 for antiskid-coated mat to soil. The dynamometer on the linkage between the mat and anchor recorded forces only after the mat began to move, and the friction between the mat and the surface it rested on was overcome since there was intentional slack in this line at the beginning of each

pull. However, by measuring the resulting forces in this link, as a backup measurement, the tests in which the antiskid to soil or antiskid to membrane occurred on the bottom mat surfaces transmitted the lowest forces to the anchor, indicating that the antiskid surface was effectively resisting mat movement.

24. Skid tests with the M19 mat were also conducted on both a smooth loess subgrade (20 CBR) and a smooth heavy clay subgrade (6 CBR) by skidding the mat on its top (antiskid surface) and bottom (painted surface) (see Appendix B). The individual panels were loaded to 2000 lb and towed at a uniform rate of speed. The coefficient of friction between the panels and the loess ranged from 0.50 to 0.65 for the painted and antiskid surfaces, respectively, and on the clay ranged from 0.73 to 0.83 for the painted and antiskid surfaces, respectively.

25. To study the behavior of mats under a skidding aircraft tire, twenty M19 landing mats were placed in five rows of four panels. The two outer rows were anchored, and a force was applied to the center row to simulate movement of the row of mat which would occur as an aircraft was braking during landing. The center row of mat was loaded both with static loads and the C-130 load cart to produce various aircraft loading conditions. Maximum loading ranged up to a 50,000-lb static load on one panel. The test was conducted on M19 mat both with and without water seals installed to determine the influence the water seals had on sliding.

26. Results of the investigation indicated that the mats without water seals gave a higher resistance to movement when subjected to a 30,000-lb load. Apparently, when a panel is loaded, the connectors distort slightly and cause binding of the mat joints in the direction of sliding. Examination of the joints after the pull tests revealed that the panels with water seals tended to remain separated in the direction parallel with the pull, whereas the panels without the seals tended to bind along these joints while sliding and thus cause higher resistance to movement. These joints contained shaved metal and nicks in the connectors indicating that a sawtooth pattern was created in the metal and caused greater resistance to movement. Thus, water seals in the M19 mat lowered the resistance and did not reduce the mat movement problem.

Traffic Tests

27. A 4- by 4-1/2-ft truss web mat was developed and designed by Dow Chemical Company to minimize the bow wave problem associated with the C-5A aircraft and also to satisfy the requirement for heavy-duty mat. It was thought that a square-configured mat with an internal geometry similar to that of the standard 2- by 9-ft truss web mat would be more compatible with the mass loadings of the C-5A aircraft. The square configuration had previously demonstrated the ability to remain relatively flat in tests utilizing the M19 medium-duty mat, and there was very little, if any, bow wave action present. Traffic tests were conducted to evaluate the 4- by 4-1/2-ft truss web mat as a heavy-duty mat.[5]

28. The mat was placed on a prepared subgrade and trafficked with a single-wheel load of 50,000 lb with a tire inflation pressure of 250 psi. In order to evaluate the mat in two different lay patterns, the test quantity of mat was divided and tested on a test section consisting of two items. A row of mat movement restrictors was placed across the test section width. The restrictors were designed to minimize horizontal mat movement due to aircraft traffic.

29. Results of the traffic tests on the 4- by 4-1/2-ft truss web mat when placed with the male/female joints running perpendicular to traffic (Dow standard lay pattern) indicated that the mat met the coverage requirement for a heavy-duty mat. The mat, when placed on a 4-CBR subgrade, will sustain 1704 coverages of the heavy-duty loading. The mat movement restrictors will sustain without damage in excess of 600 coverages.

30. A 2- by 9-ft truss web heavy-duty landing mat with waterproofable connectors was developed and designed by the Dow Chemical Company. It was thought that incorporating waterproof seals in the joints of the standard truss web mat would position all joints in an extended position, thus reducing the tendency of the mats to bow up and disengage. Traffic tests were conducted on the mat without the waterproofing seals to determine the mat's structural capability, and later the mat was traffic tested with waterproofing seals to evaluate their effectiveness.[6]

31. The truss web waterproofable mat was placed on a prepared subgrade and was tested without waterproof seals under a 50,000-lb single-wheel load with 250-psi tire inflation pressure to determine its life in coverages. Results indicated that the mat will sustain 1440 coverages of the above loading on a 4-CBR subgrade.

32. Abbreviated static tests were conducted on the 2- by 9-ft waterproofable mats to determine the effectiveness of the waterproof seals. The panels were placed on sawhorses and connected with seals installed. Water was applied to the top surface and all areas beneath the mat were observed for potential leaks. Results indicated that the seals leaked at the corners and probably along the end connector bars. Only the 9-ft seal along the male connector appeared to be waterproof. However, for this seal to perform satisfactorily, care must be exercised when connecting panels to insure that the seal remains in its proper position.

33. A small quantity of waterproofable mat with seals was placed on a 12-CBR subgrade test section which was located in an open area. The mat was tested to evaluate the effectiveness of the seals using a 26,600-lb single-wheel load with 100-psi tire inflation pressure to simulate the C-5A aircraft loading. Traffic was continued over a 2-month period during 50 in. of natural and simulated rainfall. The seals leaked during the test; however, no structural mat failures occurred. After traffic was discontinued and the mat was removed from the test section, the seals were found to be torn, dislodged, and distorted.

CONCLUSIONS AND RECOMMENDATIONS

34. In an attempt to understand and define the problems which are associated with the C-5A and landing mat, several mat configurations with various connector designs were evaluated in buckling, skid, slack, and traffic tests. Mats both with and without water seals were used in the tests; however, the heavy-duty truss web mat designs with their extra weight and additional strength were given primary consideration.

35. In the buckling tests conducted, it was determined that panel width, mat unit weight, and formation width were factors which affect the buckling load of a mat system. The horizontal load at which buckling occurs depends almost exclusively on the vertical eccentricities existing in the mat system at the time the load is applied. These eccentricities or irregularities could be initiated by the presence of warped panels, damaged joints, uneven subgrade, etc.

36. Other buckling tests revealed that the approximately square truss web mat gave much higher buckling loads than the rectangular-shaped standard truss web mat. These findings were also verified in model tests conducted by Utah State University.

37. Creeping of the runway ends toward the center, a bow wave, and in-plane bowing of a mat runway are considered critical performance of a mat system. Once an aircraft tire overruns a bow wave in a runway which is caused by compression of two or more panels, material structural failure would

most certainly occur. If the mat joints traversing the runway width are stretched to a full open position in a long runway and then restricted, then the potential hazard of in-plane bowing and buckling may be reduced. Model tests indicate that a carefully constructed runway with end anchorage appears to be a practical means of reducing maintenance on mat runways.

38. The amount of free play or slack available between the joints of mats in a runway complex varies from an average of 0.011 to 0.034 in. when placed in a normal manner with no particular attention given to the joints being tight or loose during placement. This figure can vary when consideration is given to the temperature fluctuations which might occur during the life of the airfield. The bow waves or buckling occur in areas of compressed joints. Thus, joint "stretch" has been recommended during initial mat laying. Although normally the antiskid device installed on aircraft is designed to prevent tire skidding, skidding can and does occur and tends to move mat toward the direction of landing with a cumulative action. Landings in one direction tend to open up joints on one end of the field and tighten them on the opposite end.

39. Results of skid tests indicate that necessary requirements currently imposed on an airfield to make it an all-weather operational system do not always enhance the elimination of the tendency for the runway system to move in the direction of the braking aircraft. The coefficient of friction between the aircraft tire and the mat surface coated with antiskid is higher than the value for the bottom painted surface of the mat in contact with the ground or with membrane. Thus, there is a tendency for the mat to slide on its bearing surface prior to the aircraft tire skidding on the mat surface if the panel is isolated without anchorage and joints are loose and the mat not bound by adjoining panels. Thus, some means of reducing horizontal mat movement through anchorage or some other method is required.

40. Also, membrane provides a lower coefficient of friction at the bottom of the mat compared to ground to the bottom of the mat surface, yet the membrane is a necessity beneath the mat for waterproofing unless seals are installed. Thus, the anchorage system must carry a greater load when the mat system is placed on membrane than when placed directly on soil. Antiskid on both surfaces of the mat would tend to reduce the forces transmitted to the anchors. The antiskid coating increases the coefficient of friction an average of 22 percent over that of the painted surface of the mat.

41. Both the 4- by 4-1/2-ft mat and the waterproofable 2- by 9-ft truss web mat when placed in the standard lay pattern met the coverage requirement for heavy-duty mat. Outdoor traffic tests using the C-5A loading on the 2- by 9-ft mat with seals revealed that the seals leaked; however, no structural mat failures occurred.

42. It is concluded that the approximately square truss web mat design sustained a much higher load per foot of width prior to the development of a bow wave or buckling. Square mats without water seals give higher resistance to sliding between mat rows than mats with seals. However, membrane beneath mat provides a lower coefficient of friction which enhances mat sliding. During the normal placement of mat, there is free slack in the panel joints which, although necessary for contraction and expansion, contributes to potential runway movement.

43. Based on the findings of this study and similar studies involving mats which appear capable of satisfying the C-5A aircraft requirements, it is recommended that the heavy-duty truss web mat, with inherent waterproofing and laid with the internal extrusions perpendicular to traffic and the male/female joint continuous and transverse to traffic, be developed for the C-5A. Improvements should be made to the square truss web mat and the mat field tested with the C-5A aircraft. The anchor restrictor should be tested further and also included in a field test. An end anchorage system should be developed and evaluated.

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APPENDIX A: LANDING MAT BUCKLING AND JOINT SLACK TESTS

Preface

This study was conducted as part of the landing mat program under "Environmental Constraints on Materiel, C5A Expedient Surfacing Research," DA Project No. 1T16211A131, under the sponsorship of Research Division, Research, Development, and Engineering Directorate, U. S. Army Materiel Command (now designated U. S. Army Materiel Development and Readiness Command).

The tests pertinent to this investigation were performed at the U. S. Army Engineer Waterways Experiment Station (WES) during June 1974 under the general supervision of Mr. James P. Sale, Chief, Soils and Pavements Laboratory (S&PL). Personnel of the Materiel Development Division, S&PL, actively engaged in the planning, testing, analyzing, and reporting phases of the investigation were Messrs. William L. McInnis, Hugh L. Green, Dewey W. White, Jr., and Gordon L. Carr. In addition, Messrs. James E. McDonald and James T. Peatross, Jr., of the Engineering Mechanics Division, Concrete Laboratory, conducted the buckling tests. This report was prepared by Mr. White.

Directors of WES during the conduct of this study and preparation of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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20 August 1974

MEMORANDUM FOR RECORD

SUBJECT: Landing Mat Buckling and Joint Slack Tests

1. In order to determine various movement characteristics of landing mat, buckling and joint slack tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Soils and Pavements Laboratory, on several types of landing mat designs. The buckling tests were conducted by personnel of the WES Concrete Laboratory, and the joint slack tests were conducted by personnel of the WES Soils and Pavements Laboratory.

Buckling Tests

2. Photographs 1 and 2 (Incl 1) show typical setups of the truss web mat in 9- and 36-ft-wide sections, respectively. A ram with a rated capacity of 50 kips was attached to one end of the mat section (right center of photograph 1). The opposite end of the mat section was anchored by bolts in the floor (photograph 2). During each test, the force on the ram was applied at a constant rate. The buckling loads (Incl 2) obtained for the square-type full panels (M19 and 4- by 4-1/2-ft truss web mats) in the single panel width test with the lock bar connectors parallel to the load line were slightly higher than those obtained when the lock bar connectors were perpendicular to the load line. The M19 mat, however, in the traffic coverage tests does not perform as well when the wheel load runs parallel to the lock bars as it does when the load wheel runs perpendicular to the lock bars. Tests on the 4- by 4-1/2-ft mat in a section larger than a full panel width were not conducted because mat was not available (these mat panels were being subjected to traffic tests). The buckling tests were not conducted on the 2- by 9-ft waterproof truss web mat since most of this mat was used in the traffic coverage tests and a sufficient quantity for buckling tests was not available. A section of 2- by 9-ft truss web mat 9 ft wide that buckled during the tests is shown on Incl 3. From the tests conducted, the order of increasing load, with respect to maximum buckling loads in sections wider than a full panel width, is as follows: XM18, AM2, M19, and 2- by 9-ft truss web (no buckle).

WESSS 20 August 1974

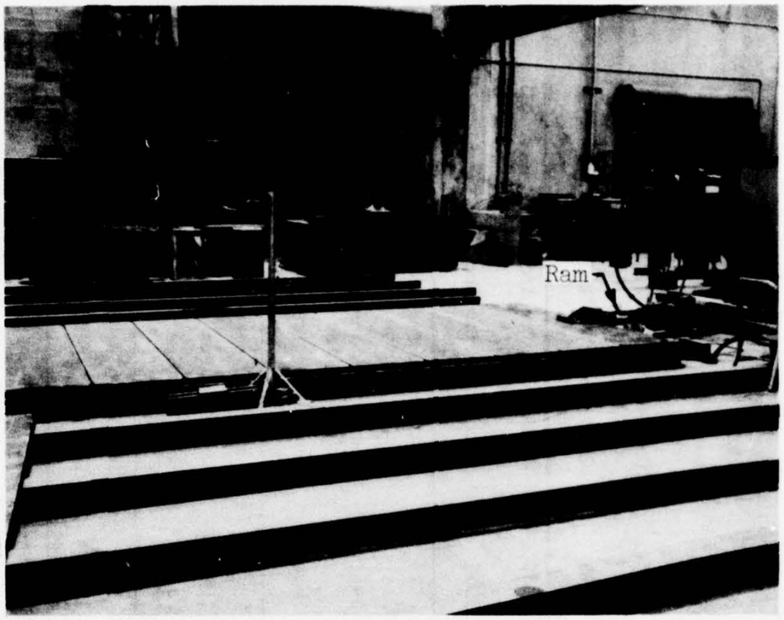
SUBJECT: Landing Mat Buckling and Joint Slack Tests

Joint Slack Tests

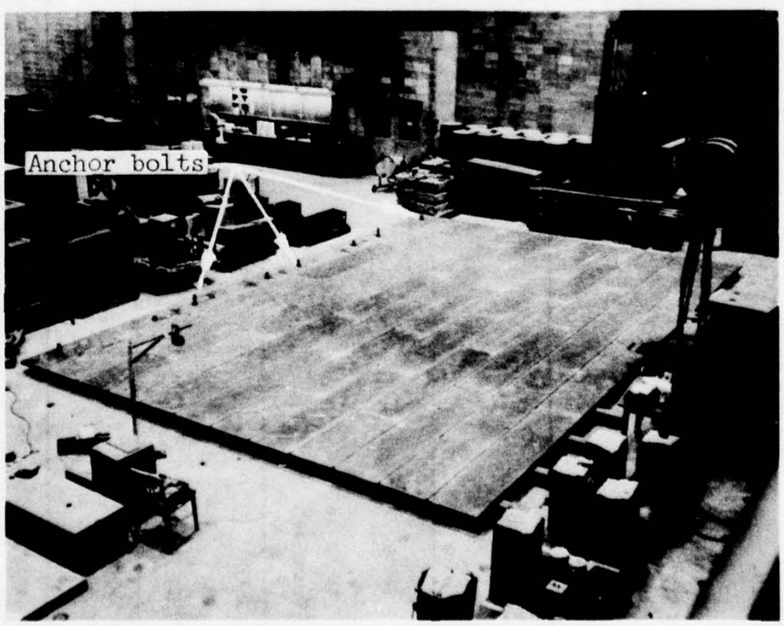
3. Tests were conducted on M19, standard truss web (2 by 9 ft), truss web (2 by 9 ft) with waterproofing seals, and 4- by 4-1/2-ft truss web mat sections to determine the amount of mat movement which would occur before all slack was taken out of ten panel joints and the last panel in the section began to move. The truss web mat was placed to determine the slack in the hinge joints (male/female) and the M19 was placed to determine the slack in the overlap/underlap joints (standard placement patterns). A typical setup for testing is shown on Incl 4. A dynamometer was used to measure the amount of force required to move the mat. All mat panels were placed normally (not jammed together or pulled to take out the slack) except for one test of the 2- by 9-ft standard truss web mat and one test of the 4- by 4-1/2-ft truss web mat. The joints of the mat panels in these two tests were jammed together in order to determine the maximum amount of movement when ten joints were placed in this manner. A summary of the mat movement in these tests is given on Incl 5. The amount of force required to move the mats depended on the weight of the mat to be moved, and the amount of movement depended on the manner in which the mat was placed. The truss web mat with seals contained some slack even though the seals tended to push the mat apart.

5 Incl
as

Dewey W White Jr
DEWEY W. WHITE, JR.
Engineer
Landing Mat Branch



Photograph 1. Test setup for 2- by 9-ft mat (9 ft wide)



Photograph 2. Test setup for 2- by 9-ft mat (36 ft wide)

Incl 2

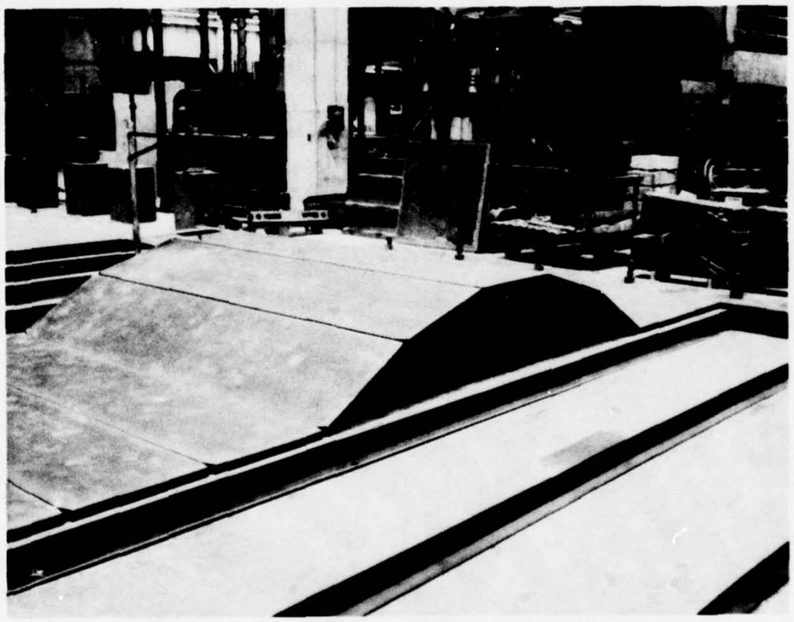
SUMMARY OF MAT BUCKLING TESTS

Test No.	Mat Type	Unit Weight lb/sq ft	Section Width ft	Section Length ft	No. of Joints	Buckling Load lb	Buckling Load /foot of Width lb/ft	Remarks
19R-4-0	M19	4.10	4.0	48	11	7,400	1850	Lock bars perpendicular to load line
TW-2S*	Truss web (4- by 4-1/2 ft)	6.28	4.0	54	11	7,900	1975	Lock bars perpendicular to load line
19-4-0	M19	4.10	4.0	48	11	7,700	1925	Connectors for lock bars parallel to load line
TW-1S	Truss web (4- by 4-1/2 ft)	6.28	4.5	52	11	11,400	2533	Connectors for lock bars parallel to load line
B-4	AM2 (2 by 6 ft)	6.10	6.0	22	11	9.900	1650	Connectors for lock bars parallel to load line
E-1	XM18 (2 by 6 ft)	4.8	6.0	22	11	11,500	1917	Connectors for lock bars parallel to load line
F-1	XM18 (2 by 12 ft)	4.8	12.0	22	11	11,700	975	Connectors for lock bars parallel to load line
C-3	AM2 (2 by 12 ft)	6.10	12.0	22	11	17,600	1467	Connectors for lock bars parallel to load line
TW-1	Truss web (2 by 9 ft)	6.3	9.0	22	11	12,580	1400	Connectors for lock bars parallel to load line
G-1A	XM18	4.8	24.0	22	11	23,500	980	Lock bars parallel to load line
D-1	AM2	6.10	24.0	22	11	25,100	1045	Lock bars parallel to load line
19S-12-0	M19	4.1	20.0	48	11	42,360	2118	Lock bars perpendicular to load line
H-1	XM18	4.8	36.0	22	11	21,070	585	Lock bars parallel to load line
TW-2	Truss web (2 by 9 ft)	6.3	36.0	22	11	63,500** (No buckle)	1764** (No buckle)	Lock bars parallel to load line

* Tests designated as TW-2S, etc., recently conducted for Landing Mat Branch. Other tests previously conducted.

** Maximum capacity of machine.

Standard lay pattern: M19 - Lock bars perpendicular to load line
XM18 - Lock bars parallel to load line
AM2 - Lock bars parallel to load line
Truss web (4- by 4-1/2 ft) - Lock bars parallel to load line
Truss web (2 by 9 ft) - Lock bars parallel to load line



Section of 2- by 9-ft mat (9 ft wide) buckled

Typical setup for mat joint slack test

FORCE REQUIRED TO REMOVE SLACK
IN TEN JOINTS OF LANDING MAT

Mat Type	Weight of Panels lb*	Force, lb		Movement in.
		Average	Maximum	
Truss web, no seals	1365	900	1065	3/32
Truss web, no seals	1365	950	1500	5/16
Truss web with seals	1288	950	1315	3/32
Truss web with seals	1288	1000	1365	5/32
Truss web, no seals	1365	900	1035	2-1/8**
M19 overlap/ underlap joint	848	700	1100	1/16
M19 overlap/ underlap joint	848	700	1050	5/32
Truss web, 4 by 4-1/2 ft	1396	1000	1150	1-29/32**
Truss web, 4 by 4-1/2 ft	1396	950	1250	11/32

* 500-lb weight was added to the last panel in each test.

** Panels were placed with joints closed for maximum movement.

NOTE: Tests were performed on a smooth heavy clay (CH) soil having a CBR strength of 12.

APPENDIX B: VARIOUS TESTS ON XM19-D1 MATS WITH AND WITHOUT SEALS

Preface

This study was conducted as a part of the work authorized by the Ground Mobility Division, Directorate of Research, Development, and Engineering, U. S. Army Materiel Command (now the U. S. Army Materiel Development and Readiness Command), under the title, "Combat Engineer Equipment," DA Project No. 1G664717DH01, Task 10, "Landing Mat Development."

The tests were performed at the U. S. Army Engineer Waterways Experiment Station (WES) during the period February-May 1971 under the general supervision of Mr. James P. Sale, Chief, Soils and Pavements Laboratory. Engineers of the Materiel Development Division who were actively engaged in the planning, testing, analyzing, and reporting phases of the study under the supervision of Messrs. William L. McInnis and Hugh L. Green were Messrs. Dewey W. White, Jr., and Gordon L. Carr. The Pavement Design Division was responsible for coordinating the test, test personnel, and equipment, under the supervision of Messrs. Richard G. Ahlvin and Cecil D. Burns. This report was prepared by Mr. Carr.

Directors of WES during the conduct of the study and the preparation and publication of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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2 June 1971

MEMORANDUM FOR RECORD

SUBJECT: Various Tests on XM19-D1 Mats with and Without Seals

Various tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) on XM19-D1 mats with and without seals. The tests and results are given on the following:

a. "Force Required to Move Connected XM19-D1 Type Mats" (Incl 1).

b. "Comparison of Coefficient of Friction of Paint and Antiskid Coating of Mats on Two Soil Types" (Incl 2).

c. "Rebound and Undulation Measurements of Waterproof XM19-D1 Mat Placed 90 deg to Normal Pattern Under C-130 Skid Test" (Incl 3).

Gordon L. Carr

3 Incl
as

GORDON L. CARR
Civil Engr Technician
Mat Section

FORCE REQUIRED TO MOVE CONNECTED XM19-D1 TYPE MATS

Water Seal Mat

1. Twenty XM19-D1 waterproof mats were placed in five rows. The outer rows were anchored to prevent movement and the center row was loaded with various weights. A force was applied to the center row of panels to produce movement. The force was measured by a 50,000-lb capacity dynamometer, and the force and distance were recorded by an electric oscillograph. Inclosure 1 shows the setup and items marked as (1) electric recorder, (2) dynamometer, (3) hooks attached to panel, and (4) reference point of anchor row. The center row of panels was loaded (1) with 2000 lb, (2) with the 30,000-lb single-wheel load cart, and (3) 50,000 lb. Inclosure 2 is a diagram of the first test and Incl 3 is a diagram of the second test. A general view of the test area is shown on Incl 4 after the third test. In test 3, the center row of mats moved a maximum of 30-7/8 in. as shown on Incl 5. The sliding of mat rows damaged the compression seal along the male connector in test 3 as shown on Incl 6. The resulting test data are tabulated on Incl 7.

2. Using the following formula, the resistance of the connected edges of mats can be computed:

$$F_1 - (P + p)\mu = F_2$$

$$\frac{F_2}{L} = C$$

where

F_1 = total force applied, lb

P = load, lb

p = mat weight, lb (840)

μ = coefficient of friction between the mat and loess subgrade of 0.5

F_2 = force resisted by edge connection of mat, lb

L = length of connected panels on two sides, ft (28)

C = connected panel resistance, lb per linear ft

In test 1, the computation using data on Incl 7 would be:

$$14{,}000 \text{ lb} - (2000 \text{ lb} + 840 \text{ lb})\ 0.5 = 12{,}580 \text{ lb}$$

$$\frac{12{,}580 \text{ lb}}{28 \text{ linear ft}} = 450 \text{ lb per linear ft}$$

In test 2, the computation using data on Incl 7 would be:

$$31{,}000 \text{ lb} - (30{,}000 \text{ lb} + 840 \text{ lb})\ 0.5 = 15{,}580 \text{ lb}$$

$$\frac{15{,}580 \text{ lb}}{28 \text{ linear ft}} = 556 \text{ lb per linear ft}$$

And in test 3, the computation using data on Incl 7 would be:

$$43{,}000 \text{ lb} = (50{,}000 \text{ lb} + 840 \text{ lb})\ 0.5 = 17{,}580 \text{ lb}$$

$$\frac{17{,}580 \text{ lb}}{28 \text{ linear ft}} = 628 \text{ lb per linear ft}$$

3. From this, it would appear that the larger load would produce more resistance to mats sliding. Some of this increased resistance is believed to be due to the fact that the larger load deforms the mats and makes the edge connection tighter and more difficult to slide.

XM19-D1 Mats Without Seals

4. Plans were to duplicate the above tests on XM19-D1 mats without the water seals for comparative purposes. Data on these tests are shown on Incl 7.

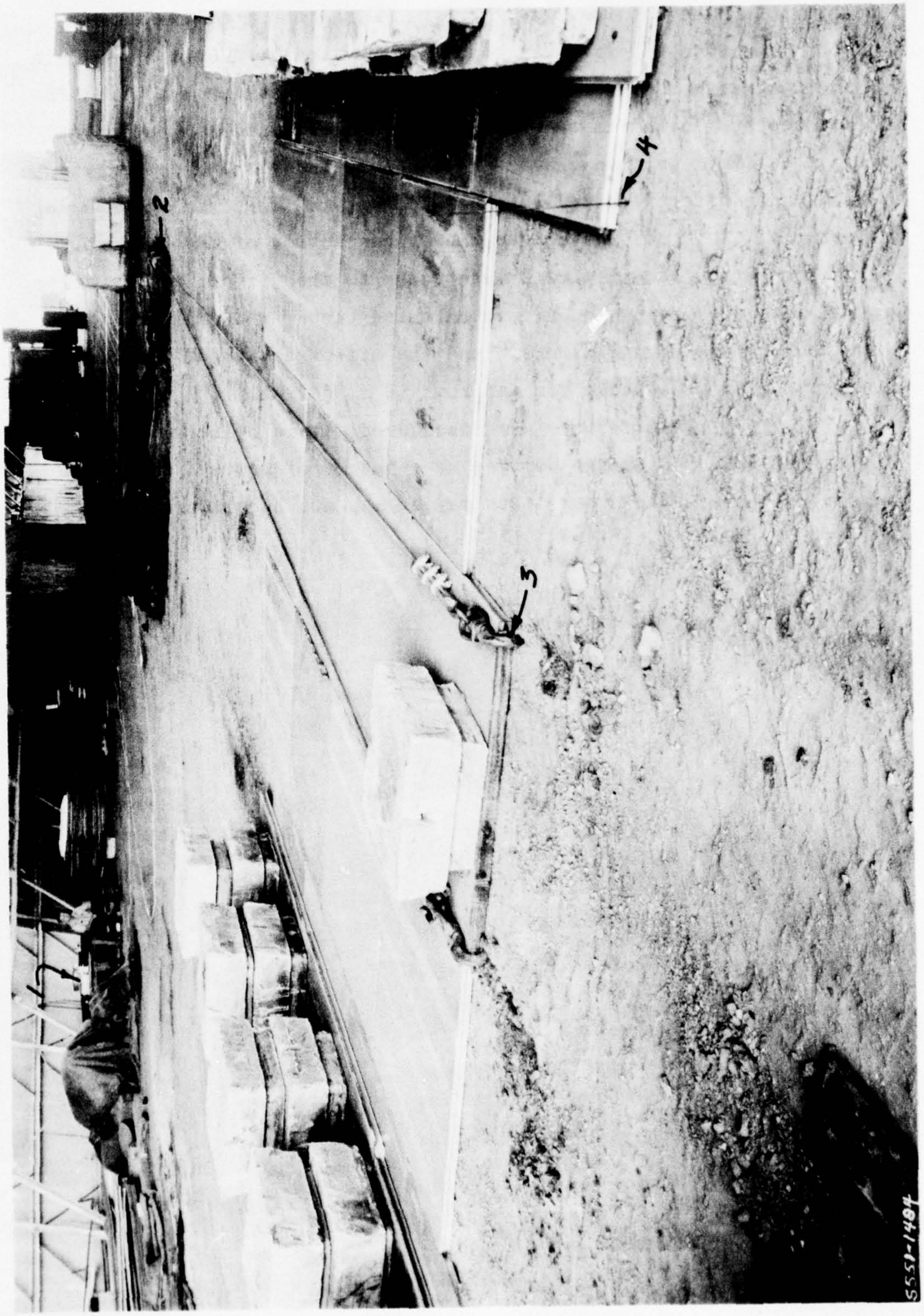
5. The 2000-lb test was performed without incident. Force was applied to move the 30,000-lb load and the 7/8-in.-diam cable was broken. The anchor row was moved 3-1/2 in. before the cable broke. It was believed that the panels were binding excessively so all panels were

taken up, examined, and relaid. The examination revealed that metal shavings were cut from the inside top and bottom along the female connector. When the panels were relaid, the mats were forced apart (stretched) at the male/female connection to eliminate shaving of the female connector and tests 6 and 7 were performed. In test 6, the 30,000-lb load was positioned on the panel where the force was applied and the drive wheels of the load cart were off of the mats. The panels were slid a distance of 2 in. by a force of 40,000 lb and the panels locked or wedged together causing the force measured to go over the scale of the recorder at 45,000 lb, stalling the caterpillar motor. In test 7, the load wheel was positioned on the center panel adjacent to the panel where the force was applied and a one-ton weight was placed on the panel receiving the force to keep the panel horizontal. When the force was applied, the panel and weight flipped up and the panel was torn and broken in half (Incl 8).

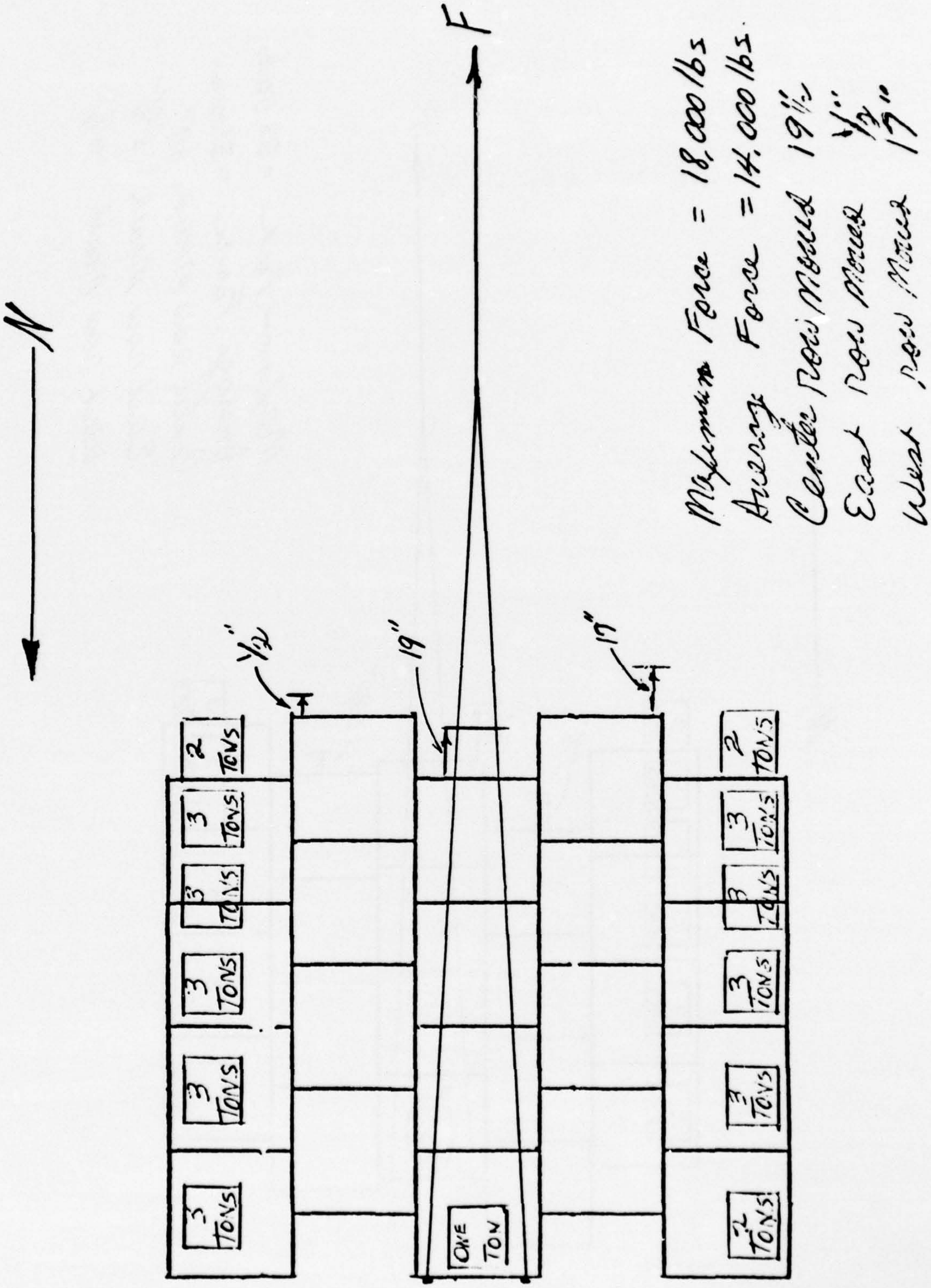
6. Comparing results of tests 1 and 4 indicates that the water seals increase the mat's resistance to slide from 242 to 450 lb per linear ft of connected mat or by 86 percent. Results of comparing tests 2 and 6 indicate an opposite conclusion. The mats without seals increase the mat's resistance to slide from 556 to 876 lb per linear ft of connected mat or by 57 percent. A suggestion as to what caused the mats without seals to resist greater sliding forces follows. The initial panels without seals were placed normally (random tight and loose) as opposed to the water seal mats all being placed tight (extended apart by the compression seal). When a row of mats without seals was slid, each panel adjacent to the sliding row, acting individually, would alternately slide and cock, producing a jagged sawtooth pattern that required greater forces to slide the mats. This is illustrated (greatly exaggerated) on Incl 9. The comparison, giving directly opposite results or conclusions, indicates that the data were inconclusive. However, when the following is noted and considered, one of the above conclusions can be partly acceptable or recommended for further consideration: (a) The mat at Dyess AFB without seals slid under aircraft operations; however, the Dyess mats did not have the modified female

connector; (b) The mat in these (WES) tests had the modified female connector and were in excellent condition but had been used as fill-in mat during traffic tests. Comparison of the original and modified female connectors indicates that connecting features and contact points or areas of the mats when placed are the same and should not contribute to sliding or affect the panels when sliding; (c) The overlap-underlap connector of the Dyess mat versus the D1 connection of the WES mat, with joints discontinuous and placed transverse to the direction of traffic, was considered as having no effect on these tests; and (d) The vibration induced by a moving aircraft and the off-on action of the brakes contribute to the tendency for mat rows to slide.

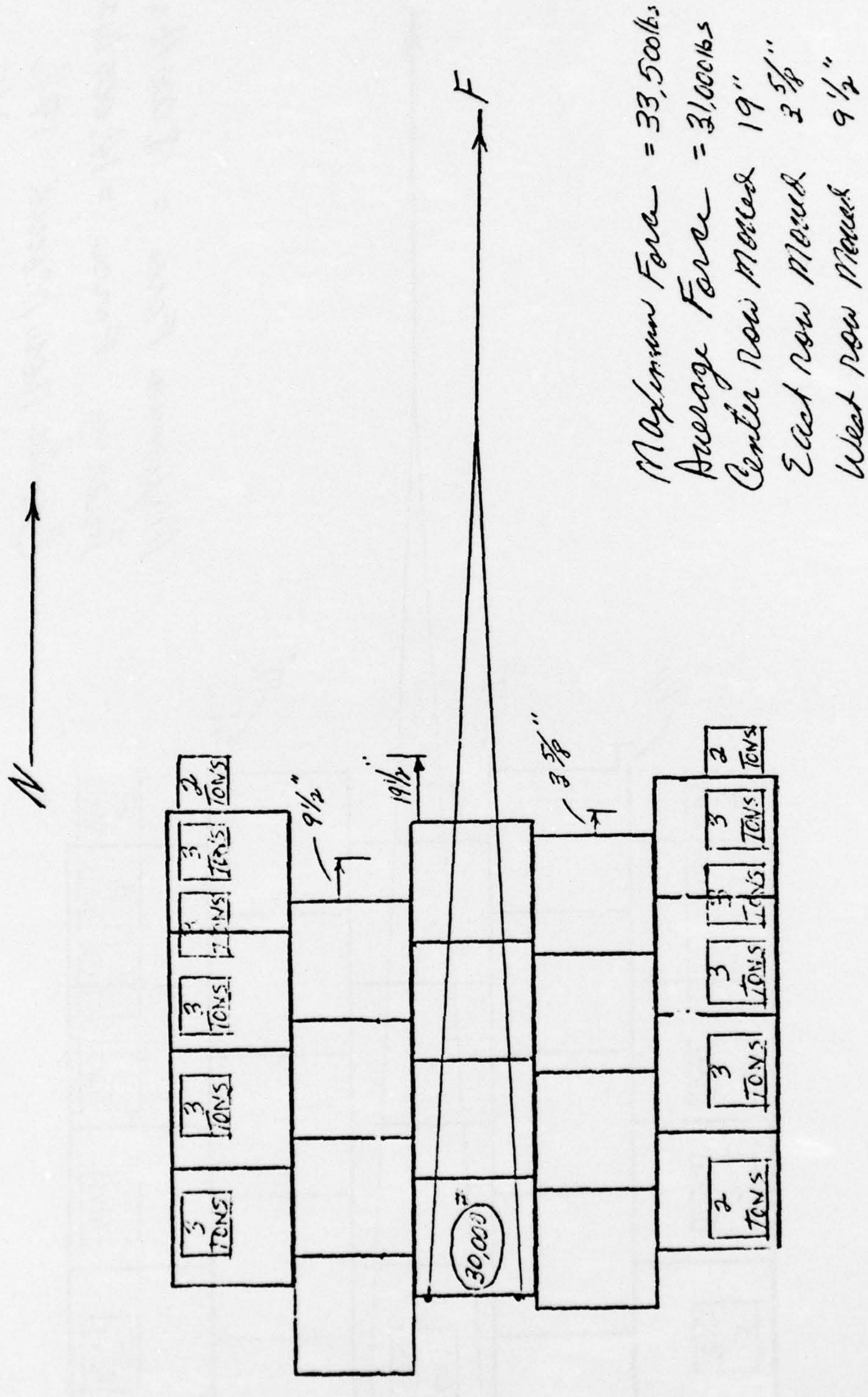
7. After these factors are considered, it is believed that the comparisons and conclusions derived as a result of tests 1 and 4 are reasonably valid. The other tests may or may not be comparable.



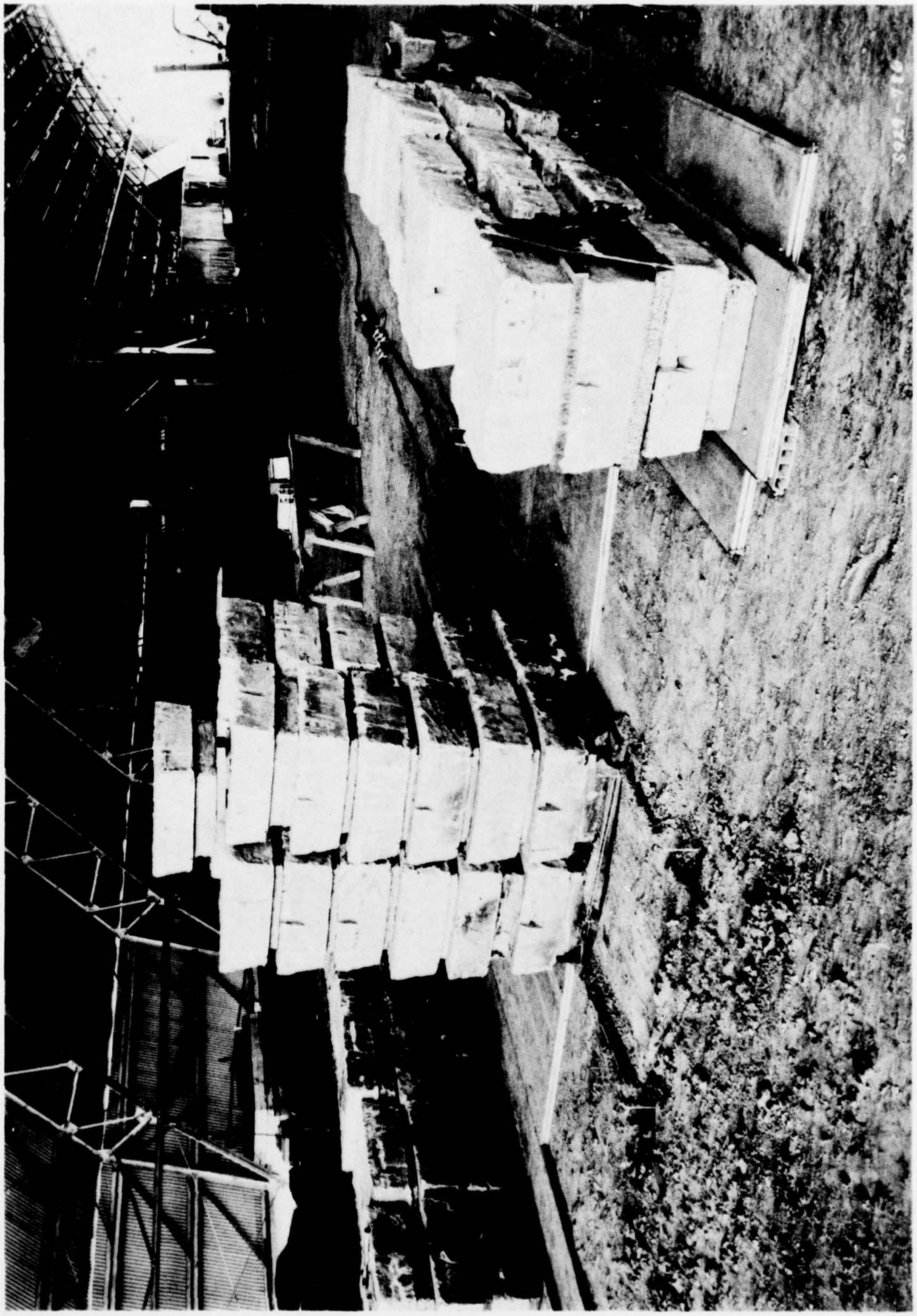
Incl 1 to Incl 1



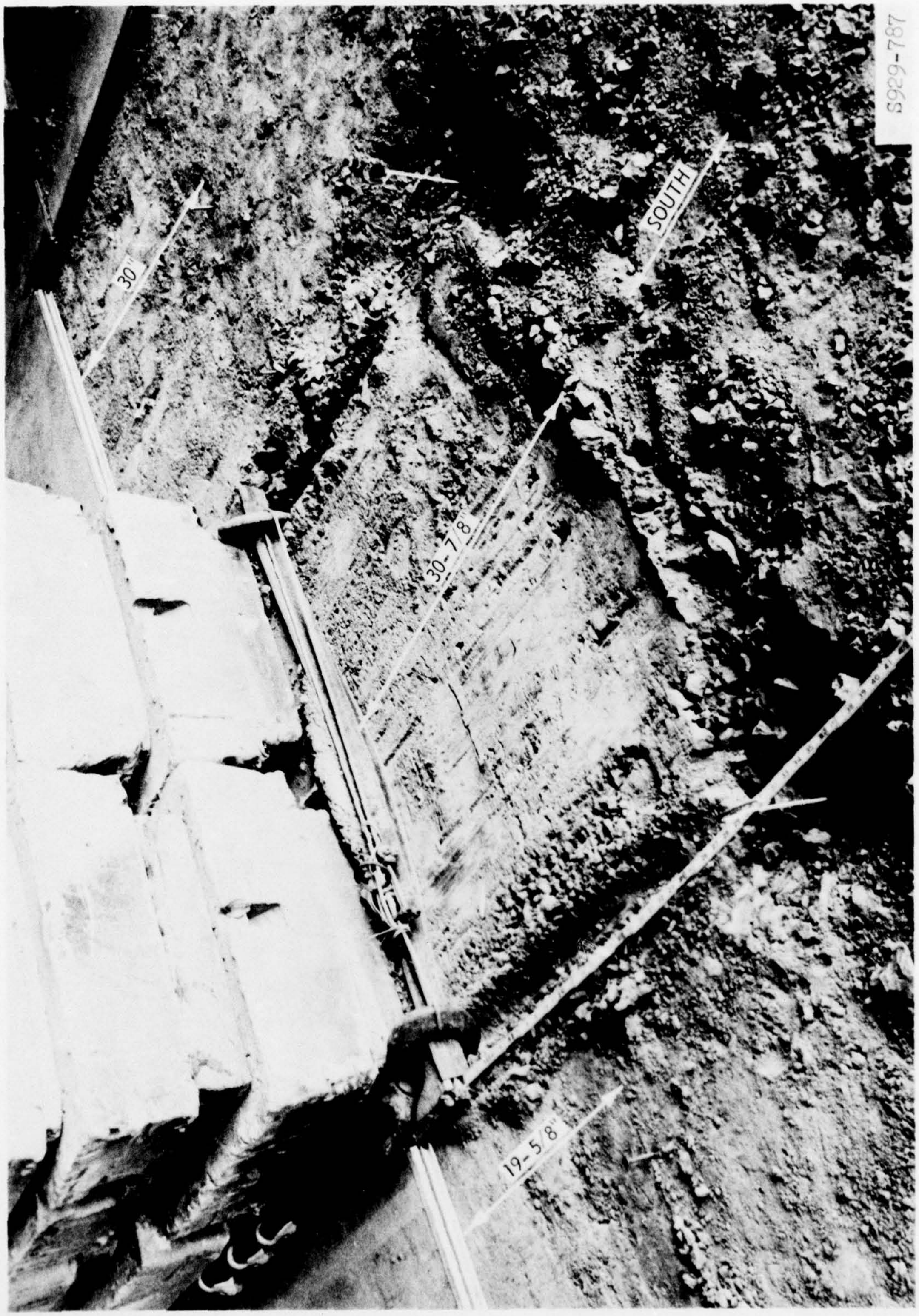
Incl 2 to Incl 1



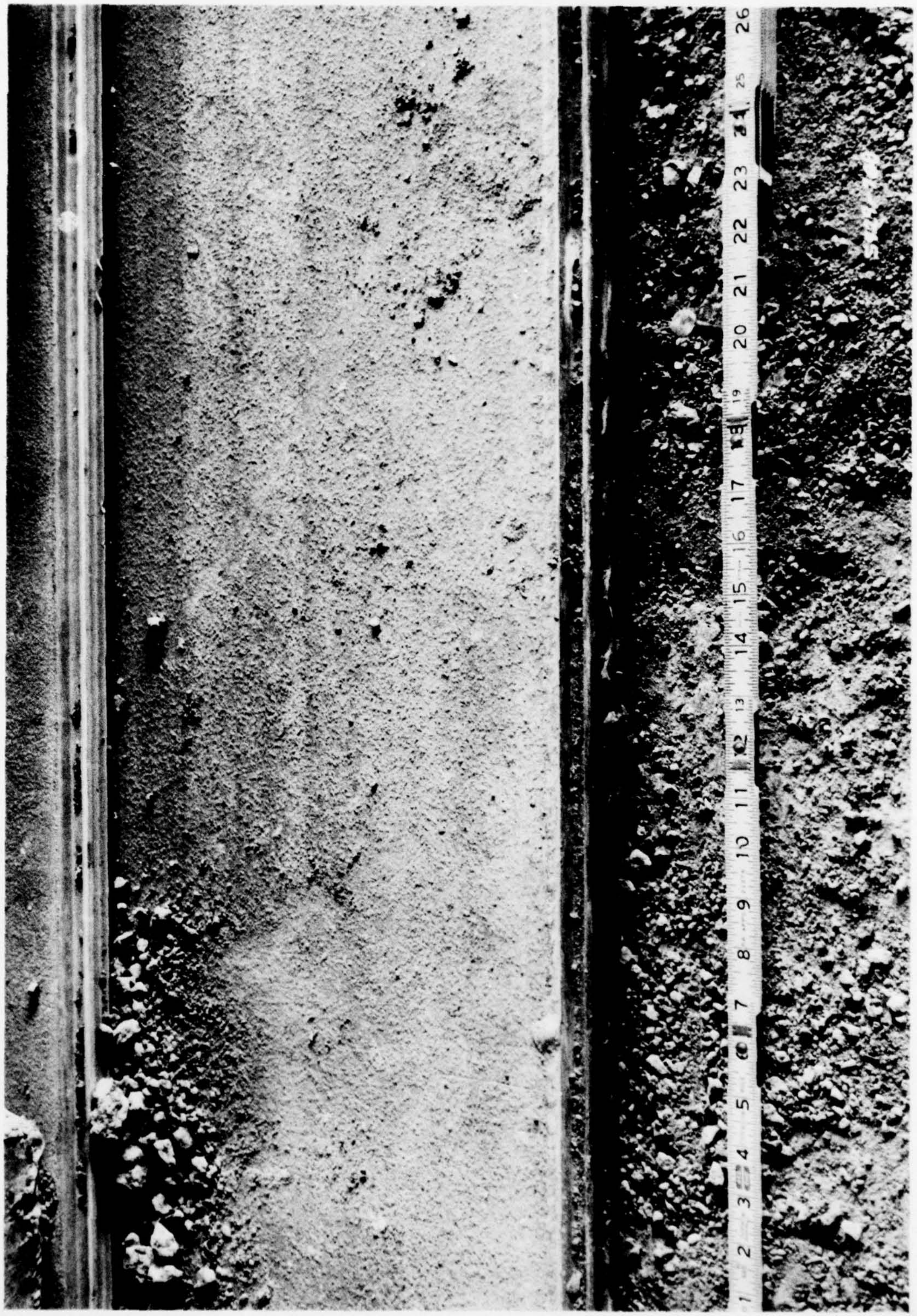
Incl 3 to Incl 1



Incl 4 to Incl 1



Incl 5 to Incl 1

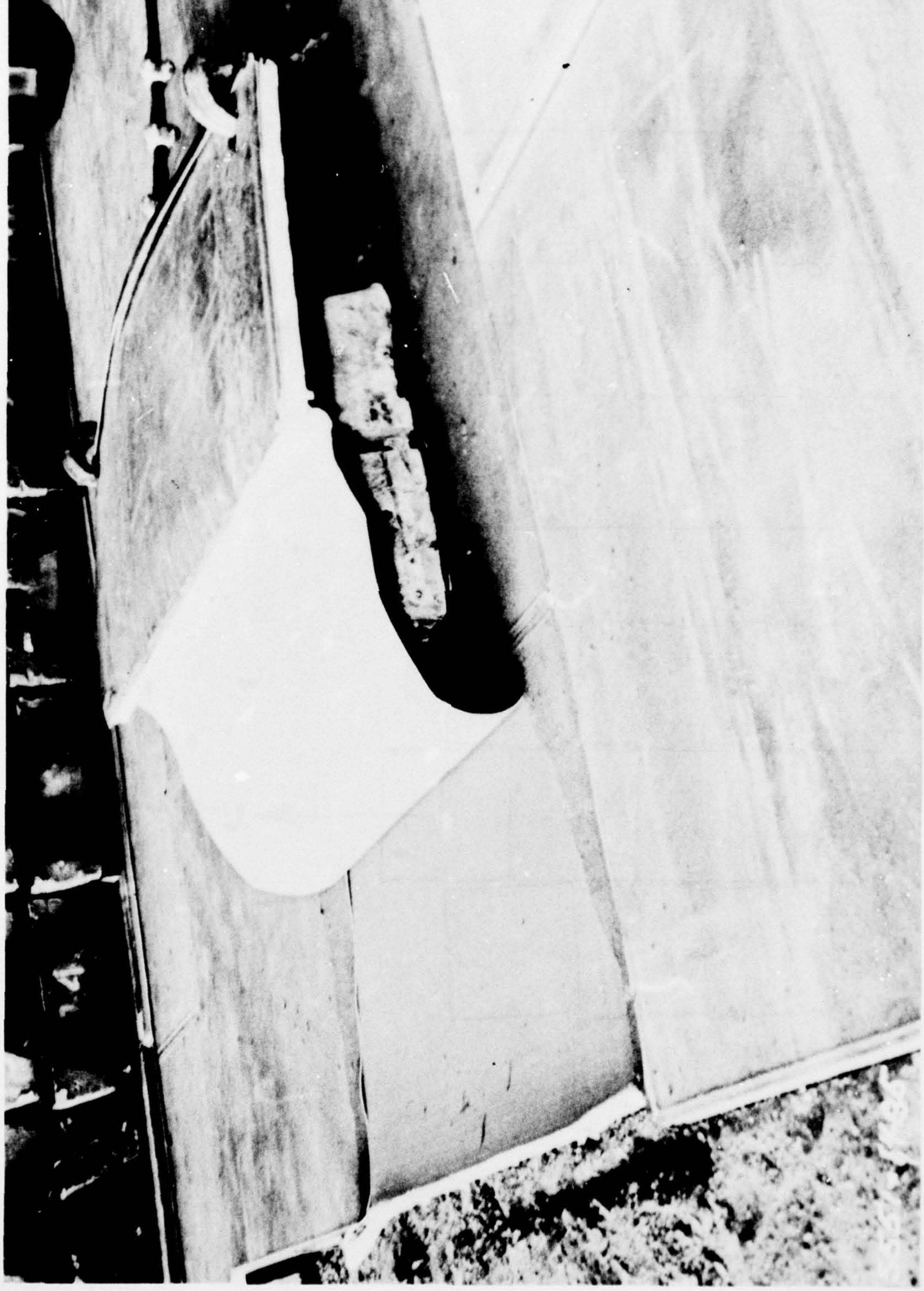


Incl 6 to Incl 1

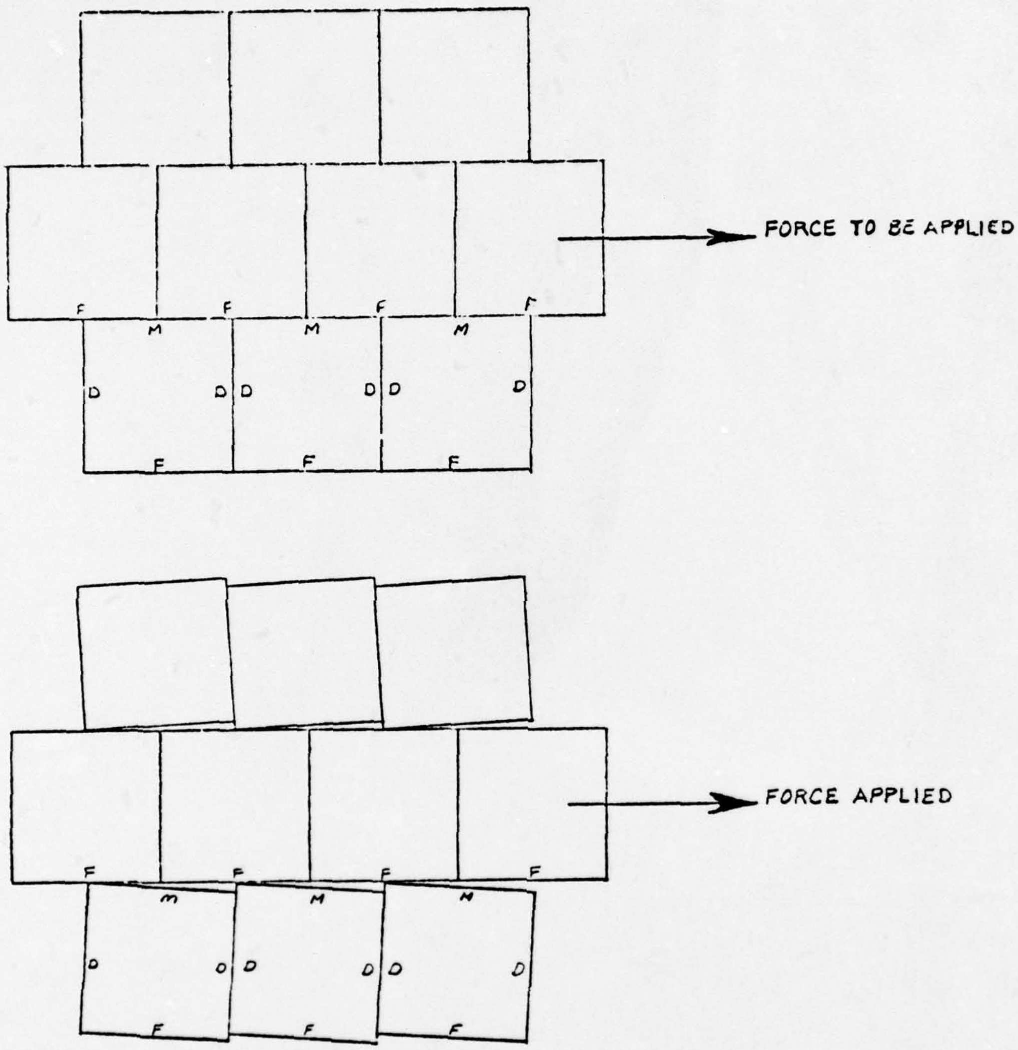
Sliding Rows of Connected Mat Data

Date 1970	Test	Load Conditions	Time Sec	Distance ft	Peak Load lb	Average Load lb	Load per Linear ft of Connected Mat, lb	Remarks
				XM19-D1 Waterproof Mat with Seals				
23 Apr	1	2,000	5	1-1/2	18,000	14,000	450	20 panels connected (Incl 1)
23 Apr	2	30,000	13	1-1/2	33,500	31,000	556	20 panels connected. Two rows of mat adjacent to center row removed.
7 May	3	50,000	9	2-1/2	49,000	43,000	628	Three rows between anchor rows moved. Compression seal in male connector damaged on west row (Incl 6).
				XM19-D1 Mat Without Water Seals				
10 May	4	2,000	5	2-1/3	8,500	8,200	242	Panels were in a severe bind at end of test. Metal shavings were removed from the inside bottom and top of the female connector.
10 May	5	30,000	-	--	--	--	--	East anchor row moved 3-1/2 in. and 7/8-in.-diam cable broke. 13 tons were used on each anchor row.
11 May	6	30,000	1-2	1/6	42,000	40,000	878	Each anchor row was anchored with 24 tons. Cat was chocked down after initial movement and the recorder went over scale range (45,000 lb).
11 May	7	30,000*	-	0	42,000	--	--	The panel on which the force was applied flipped up and broke in half (Incl 8).

* A one-ton weight was placed on the panel where the force was applied and the 30,000-lb single-wheel load was on the adjacent panel.



Incl 8 to Incl 1



MAT REACTION

Incl 9 to Incl 1

COMPARISON OF COEFFICIENT OF FRICTION OF PAINT AND ANTISKID COATING OF MATS ON TWO SOIL TYPES

One panel of XM19-D1 was loaded with 2000 lb and a force was applied to move the loaded panel at a uniform rate of speed. A 5000-lb capacity dynamometer was used to measure the force applied, and the force and distance were recorded by an electric oscillograph. The bottom of the panel (painted) and the top of the panel (antiskid coated) were in contact with the soil on duplicate tests. These tests were performed on both a smooth loess subgrade (approximately 20 CBR) and a smooth heavy clay buckshot subgrade (approximately 6 CBR). These data are tabulated in Incl 1, and are summarized below.

The painted surface on the loess gave a coefficient of friction of 0.5.

The antiskid surface on the loess gave a coefficient of friction of 0.65 or an increase of 30 percent over the painted surface.

The painted surface on the buckshot gave an average coefficient of friction of 0.73.

The antiskid surface on the buckshot gave an average coefficient of friction of 0.83 or an increase of 14 percent over the painted surface.

Conclusions: The antiskid coating will increase the coefficient of friction from 14 to 30 percent over the painted surface of a mat, depending on the type of subgrade material.

Mat Surface Coefficients of Friction

Test No.	Load lb	Time Seconds	Distance ft	Force, lb Peak	Force, lb Average	Coefficient of Friction (μ)	Remarks
1	2000	13	20	1300	1000	0.5	Bottom of mat on loess soil
2	2000	13	21	1300	1000	0.5	Bottom of mat on loess soil
3	2000	13	18	1700	1300	0.65	Antiskid surface on loess soil
4	2000	15	20	1700	1300	0.65	Antiskid surface on loess soil
5	2000	10	5	1900[1]	1500	0.75	Bottom of mat (painted) on heavy clay (buckshot)
		10	5	2300[2]	2000	1.0	See Note
6	2000	9	6	1700[1]	1500	0.75	Bottom of mat (painted) on heavy clay (buckshot)
		9	6	2400[2]	2100	1.1	
7	2000	9	6	1700[1]	1400	0.70	Bottom of mat (painted) on heavy clay (buckshot)
		9	6	2800[2]	2300	1.2	
8	2000	18	12	1900	1600	0.8	Antiskid surface on heavy clay (buckshot)
9	2000	15	12	2200	1700	0.85	Antiskid surface on heavy clay (buckshot)

NOTE: (1) First half of test
(2) Second half of test as panel dug into soil

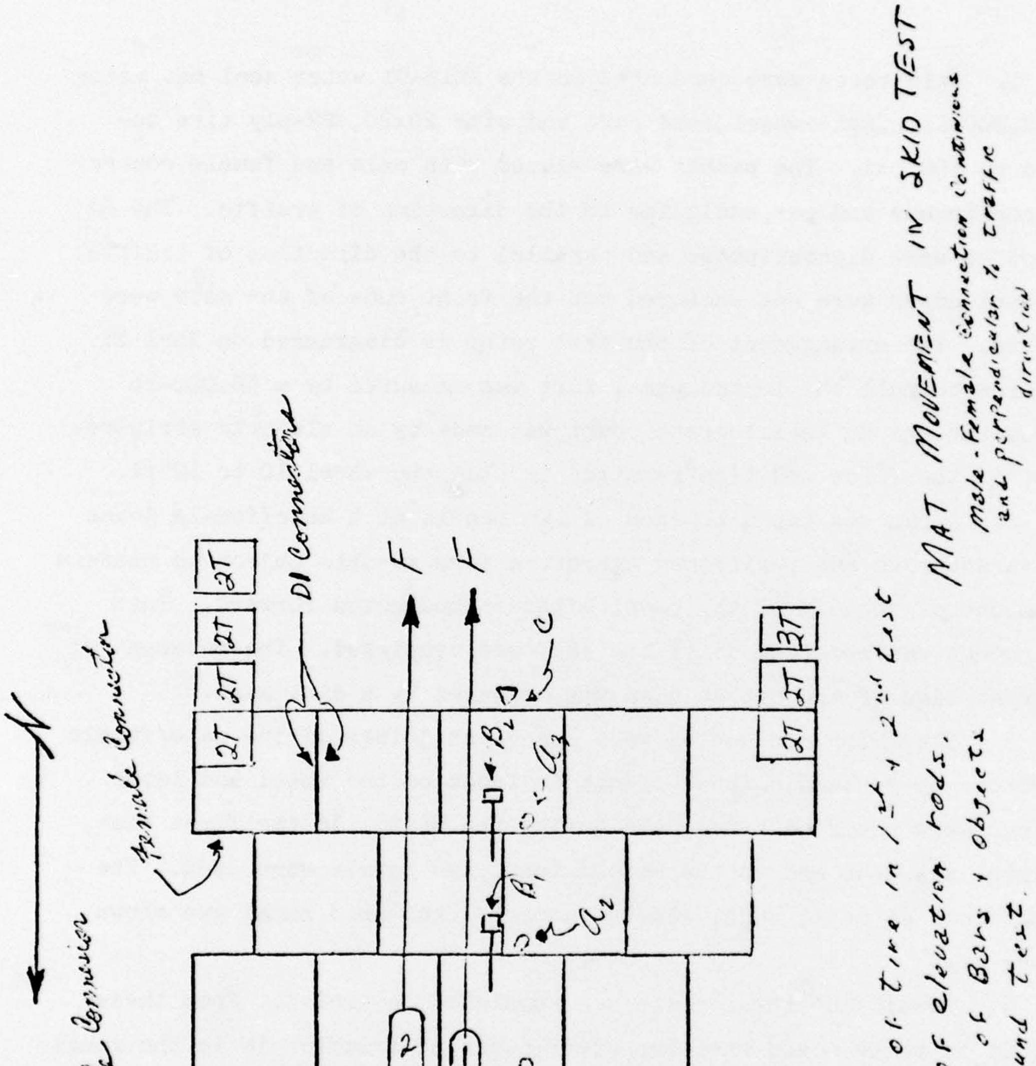
REBOUND AND UNDULATION MEASUREMENTS OF WATERPROOF XM19-D1 MAT
PLACED 90 DEG TO NORMAL PATTERN UNDER C-130 SKID TEST

1. Skid tests were conducted on the XM19-D1 water seal mat using the 30,000-lb single-wheel load cart and size 20x20, 22-ply tire inflated to 100 psi. The panels were placed with male and female connectors continuous and perpendicular to the direction of traffic. The D1 connectors were discontinuous and parallel to the direction of traffic. The panel edges were not anchored but the front ends of the mats were anchored. The arrangement of the test setup is diagrammed on Incl 1. The force to pull the locked wheel cart was measured by a 50,000-lb dynamometer and an oscillograph chart was made by an electric strip recorder of the force and time required to skid the wheel 10 to 12 ft.

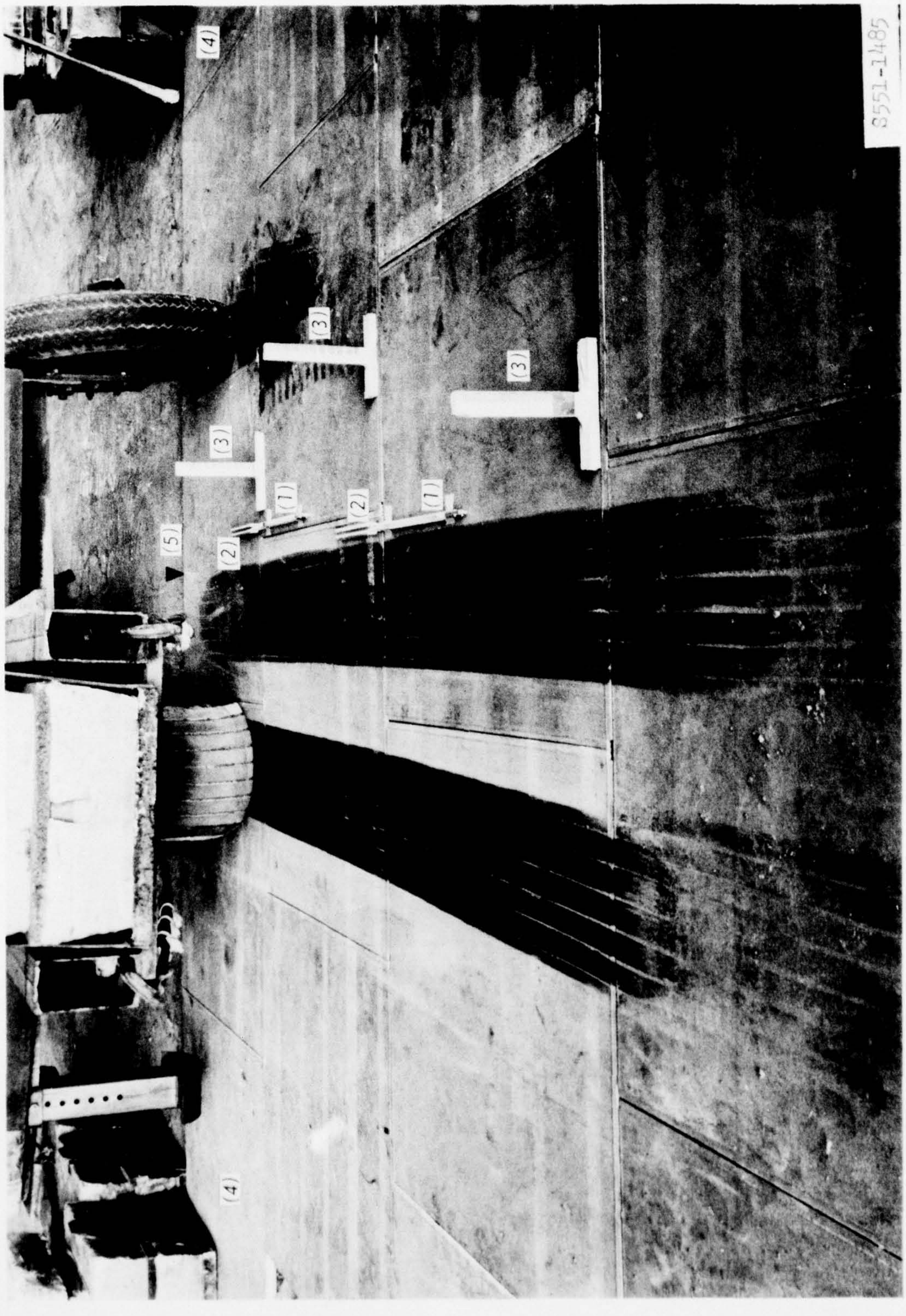
2. A bar was taped to each of two panels at a male/female joint on adjacent rows and positioned against a firm movable object to measure the amount of rebound of the panel after it had moved forward. This measurement was recorded after the skid was completed. The movement of the front edge of the mat section was measured by a dial gage.

3. Elevation rod scales were placed at joints of the male/female connectors on succeeding rows of mat in front of the wheel and level readings were recorded before and during the test. In the first test, one level was used and in the second test, two levels were used. The arrangements of mats, rods, scales, anchors, and skid marks are shown on Incl 2.

4. Results of these tests are tabulated on Incl 3. From these data, it is to be noted that the coefficient of friction is in the range of that recorded in previous tests. The maximum elevation of the panel joint is when the lock wheel enters on a panel and the opposite edge is forced up. The maximum amount of upward movement was measured at 0.6 in. The mat goes down if there is a void of soft subgrade when the tire is on that void of soft subgrade. The mat rebounded only 0.06 in. after the front edge of the mat had moved forward 0.250 in. in test 1. No forward movement was noted in test 2, and no rebound recorded. The joints were probably tight after test 1 and no additional slack was available for movement in test 2.



Incl 1 to Incl 3



Incl 2 to Incl 3

Skid Test on XM19-D1 Water Seal Mat

Test No.	Distance ft	Force, lb Peak	Force, lb Average	Coefficient of Friction μ	Elevation, in. Interval	Elevation, in. 1st Rod	Elevation, in. 2d Rod	Position of Wheel When Elevation Recorded*	Movement of Front Edge of Mat, in.	Rebound in.
1	12	23,000	17,500	0.57	High		2.0	A	1/4	0.060
					Start		1.4	-		
					Low		1.4	B		
					Change		0.6			
2	10	26,500	18,000	0.60	High	4.4	3.8	A	--	None
					Start	3.8	3.3	-		
					Low	3.8	3.0	B		
					Change	0.6	0.8			

* A = Wheel on edge of panel when level on opposite side of panel was read
B = Wheel on joint when level rod at same joint was read

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Green, Hugh L
Summary of buckling and tension tests of landing mats as related to C-5A aircraft bow wave problems, by Hugh L. Green [and] Carroll J. Smith. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
12 p. illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper S-77-1)
Prepared for U. S. Army Materiel Development and Readiness Command, Alexandria, Va., under Project No. 1T162112A528, Task 04.
References: p. 12.
Appendices: A. Landing mat buckling and joint slack tests.- B. Various tests on XM19-D1 mats with and without seals.
1. Aircraft tires. 2. Bow waves (Landing mats). 3. Buckling. 4. C-5A aircraft. 5. Joints (Junctions). 6. Landing mats. 7. Seals (Stoppers). 8. Skid resistance. 9. Sliding friction. 10. Waterproofing. I. Smith, Carroll J., joint author. II. U. S. Army Materiel Development and Readiness Command. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper S-77-1)
TA7.W34m no.S-77-1